Toward Long Lasting, Durable Bridge Decks

Acknowledge Contributions from Ron Walker, Neal Carboneau, Tony Zander, Tommy Nantung

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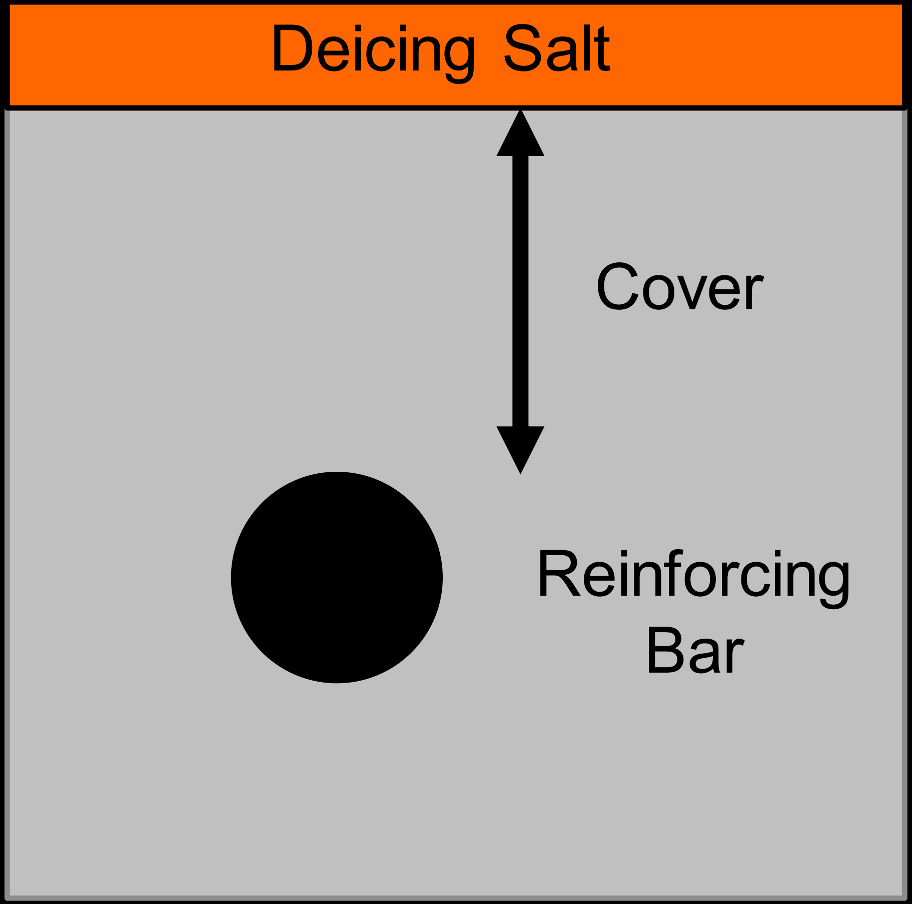
Professor & Director of the Pankow Materials Laboratory

Salt Usage Abounds

- Before 1940’s, removal of snow and ice used plowing, salt and cinders
- 1950-60’s bare pavement policy implemented
- 1970’s deicing salts become widely used to maintain clear pavements
- US - salt is the most widely used deicing material with 8-12 million annual tons

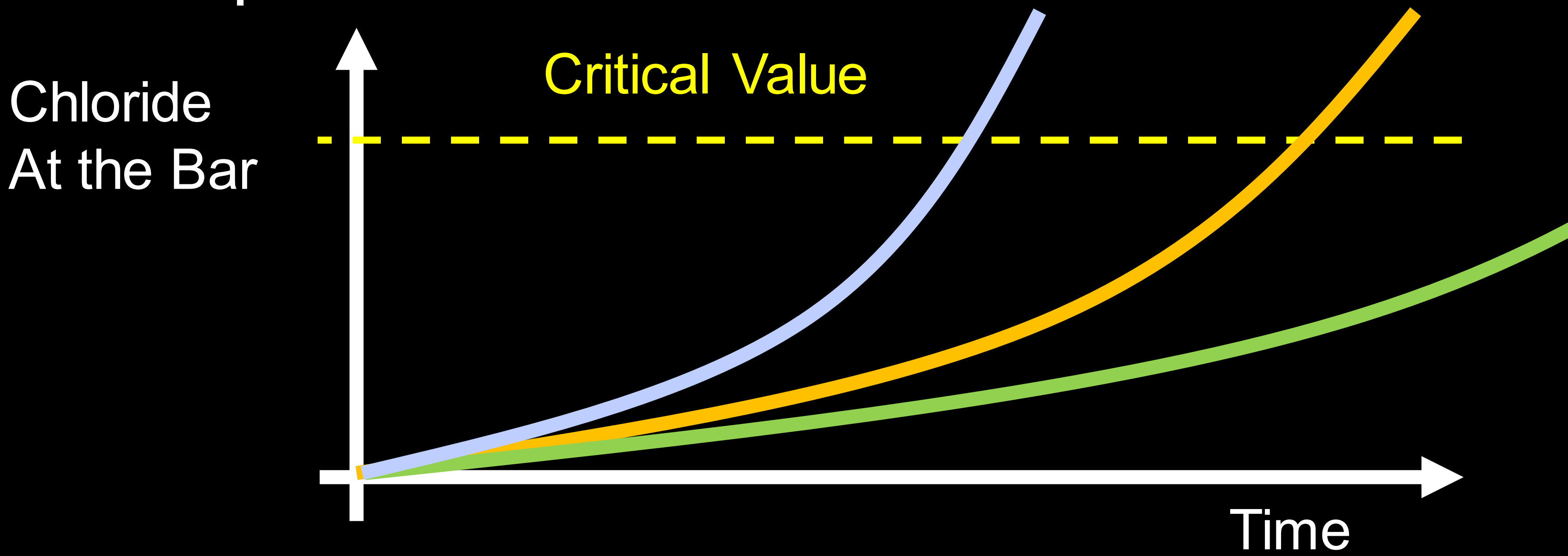
Durability Related to Transport



- Salt can be absorbed or can diffuse in the pores and when it reaches the rebar it can depasivate the steel and cause corrosion

How Long Does for Corrosion to Start

- The chloride will migrate to the bar over time
- How long does it take to reach a critical level
- Depends on the quality of the concrete and the depth of the reinforcement



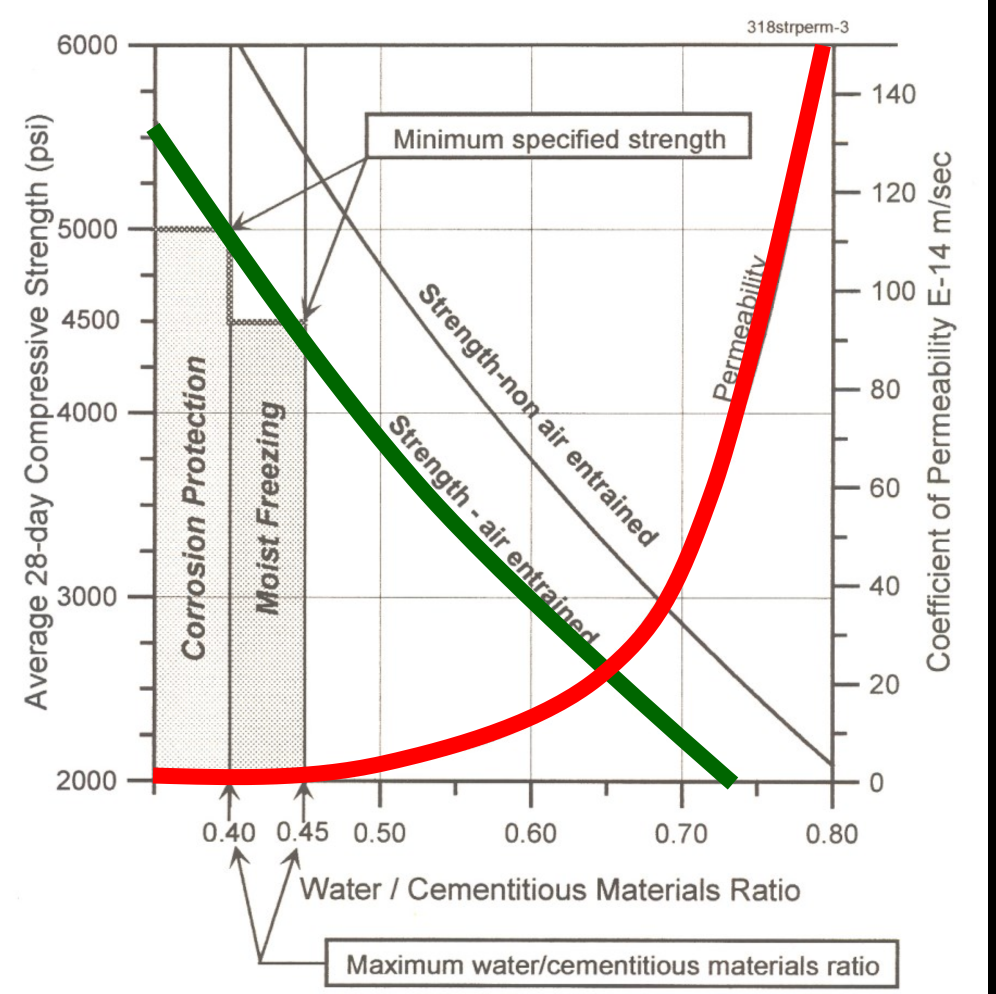
Various Strategies to Extend Time

- Higher Strength
- Sealers
- Overlays
- Coated Bars

Reducing Transport

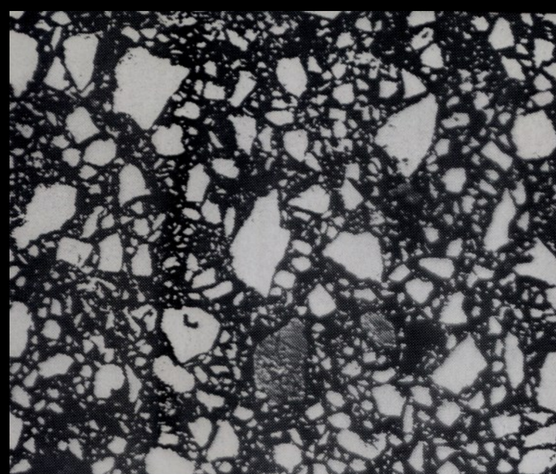
- Strength is related to w/c; transport properties are even more strongly influenced
- WRA, SCM, SF all densify concrete
- Why is this the case and what else may change

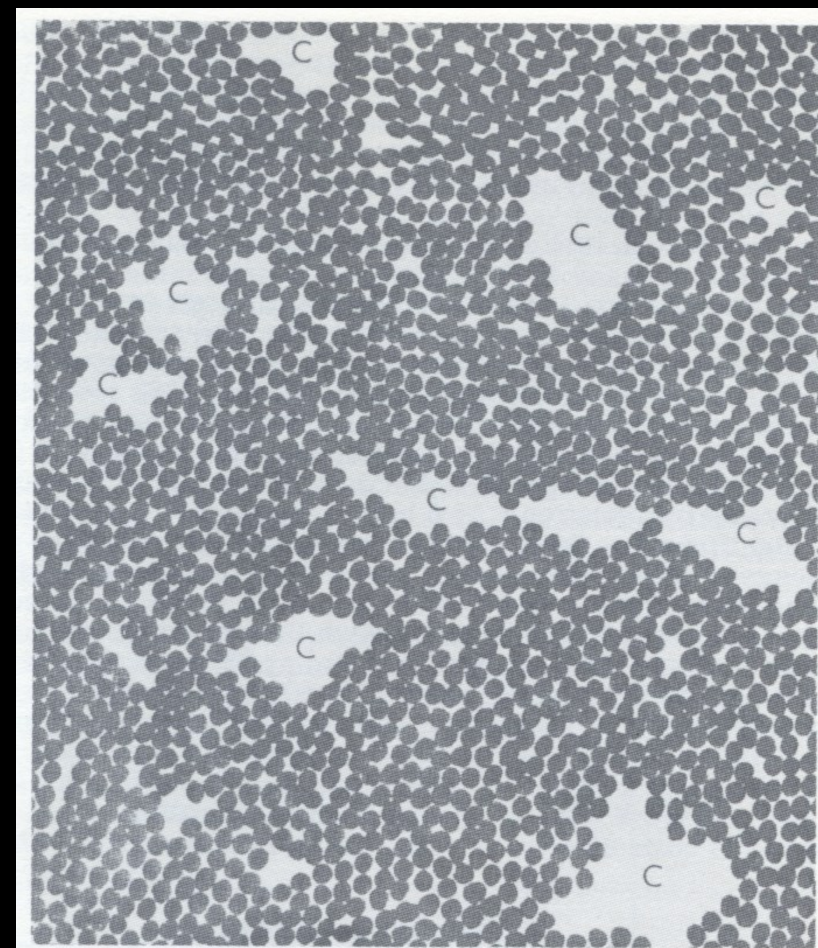
After ACI 318 From Hover 2003



A Pore Structure Argument for Why We Want Higher Strength Concrete

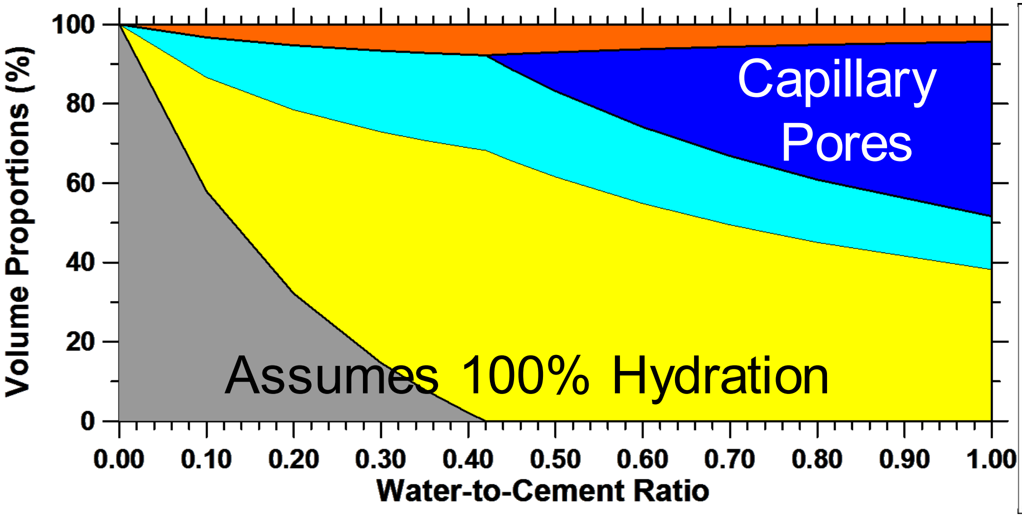
- Concrete is a Porous Material
- Two Types of Pores
  - Capillary Porosity (Big Pores Mix Water, Fill in Over Time)
  - Gel Porosity (Small Pores - Hydration)

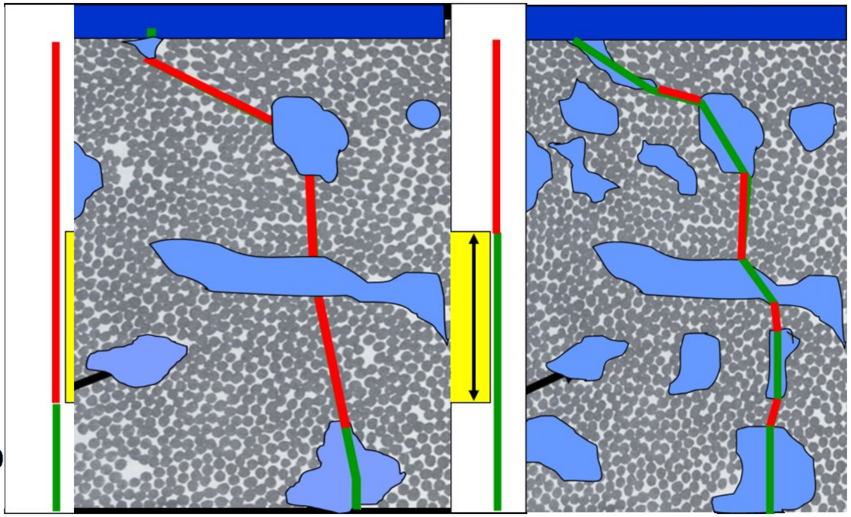




Transport in Large Pores, Shrinkage from Small Pores

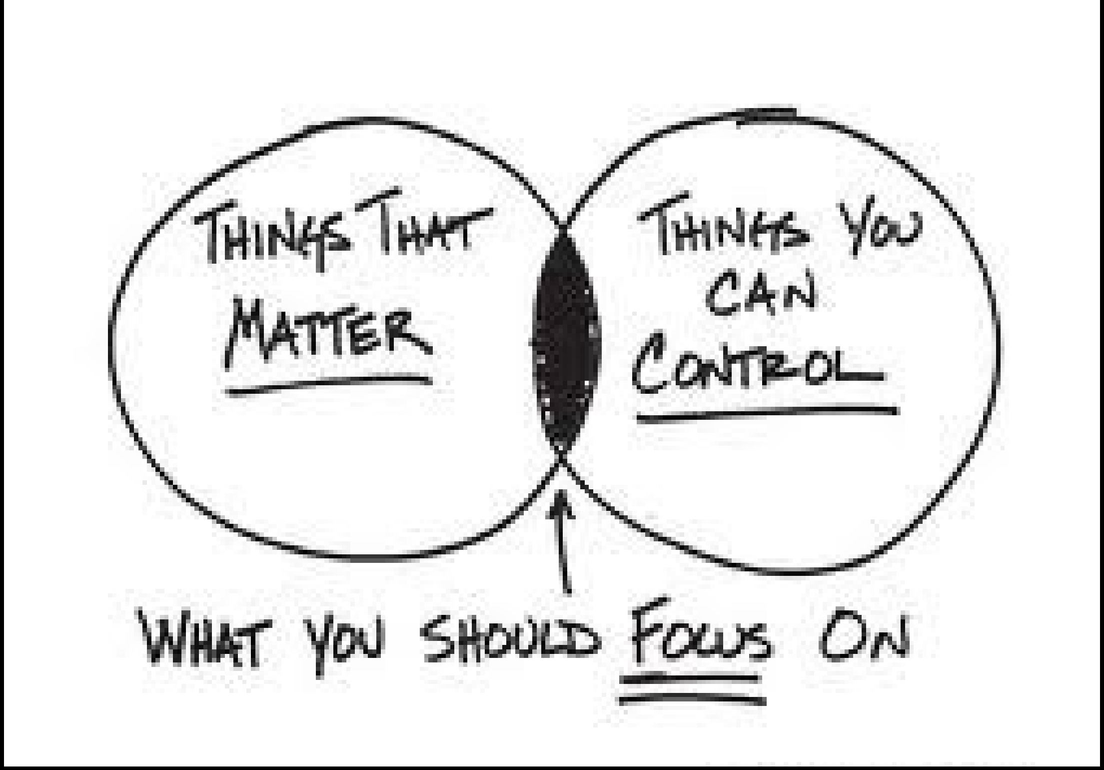
- Transport occurs through capillary pores
- Capillary pores – large and connected
- Low w/c - smaller pores – improves strength and improves transport
- But what about the influence on other properties





What Can We Control

- We can control the capillary pores by controlling the w/c (SCM and WRA good)
- We should do this when we can
- Excess water leads to pores and increased transport
- Low w/c = HSC



Higher Strength
Why Do We Want It

- "**High-strength** concrete is one of the most significant new materials available to federal, state, and local highway agencies………... With its improved **impermeability, durability, and accelerated strength** gain …….. an ideal material ….."
- HSC **may be slightly more expensive** than normal concrete initially, but its greater strength means that HSC bridges may require **fewer supports**, which could **reduce overall costs**.

Benefits of High Strength Concrete

Advantages

- Higher Strength
- Rapid Strength Gain
- Low Permeability
- Improved Durability
- Costs
- Less Members
- Ease of Placement
- Volume Stability
- Toughness
- Higher Modulus
- Lower Creep

Disadvantages

- Costs

It'll knock your socks off..
And it'll get'em whiter

Asking for Higher Strength with the Best of Intentions….

True or False:

Increasing Strength Improves Performance

………Misconceptions of Using Lower W/C, Higher Strength Concrete

Is All High Strength Concrete Evil ??

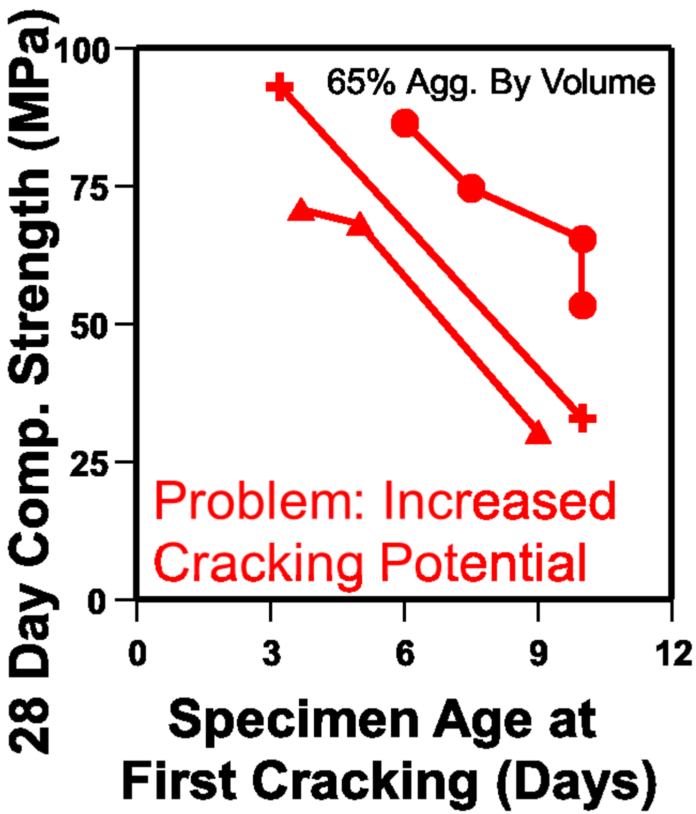
Obviously No

- High Quality Concretes Can Be Made with High Strength, However

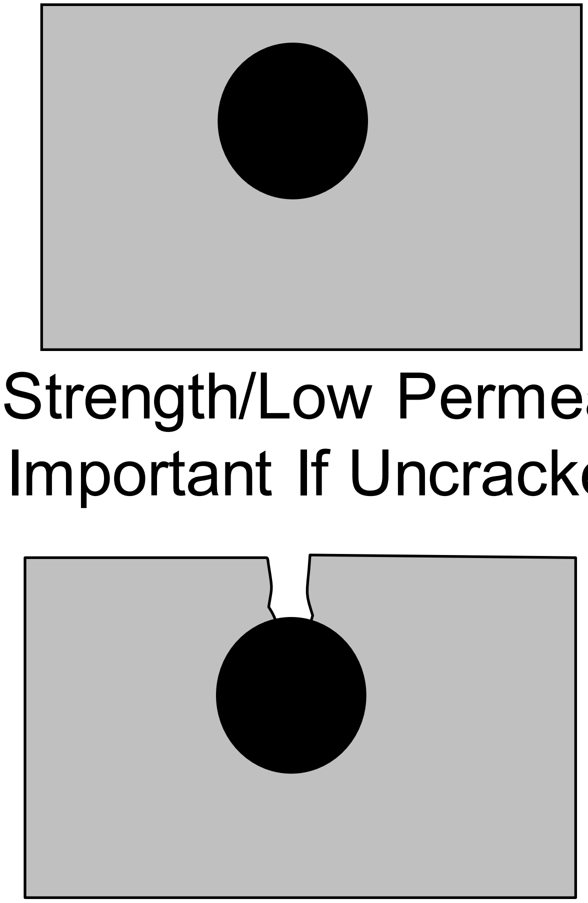
Be Prepared for What You Ask For

- Additional Problems May Arise

Low Transport ….. Between the Cracks



Weiss 1997



High Strength/Low Permeability is Important If Uncracked

Not so Important once the Section has Cracks

Advantages

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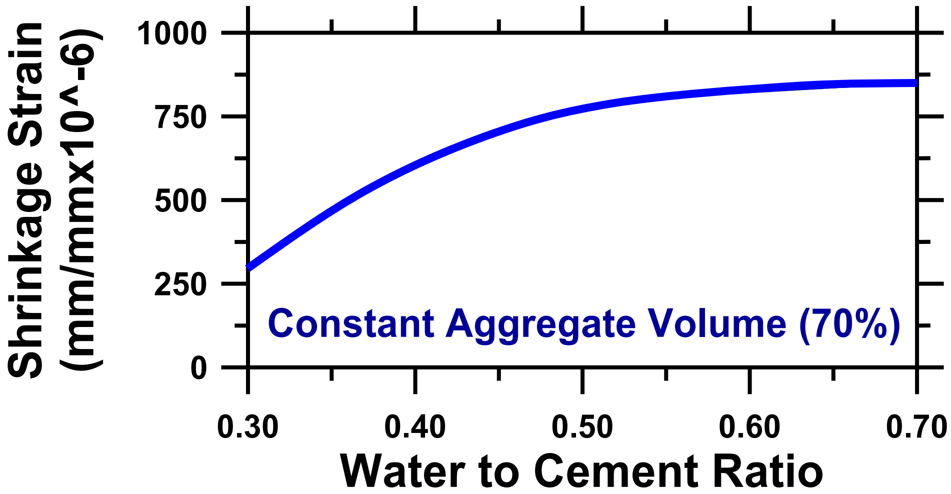
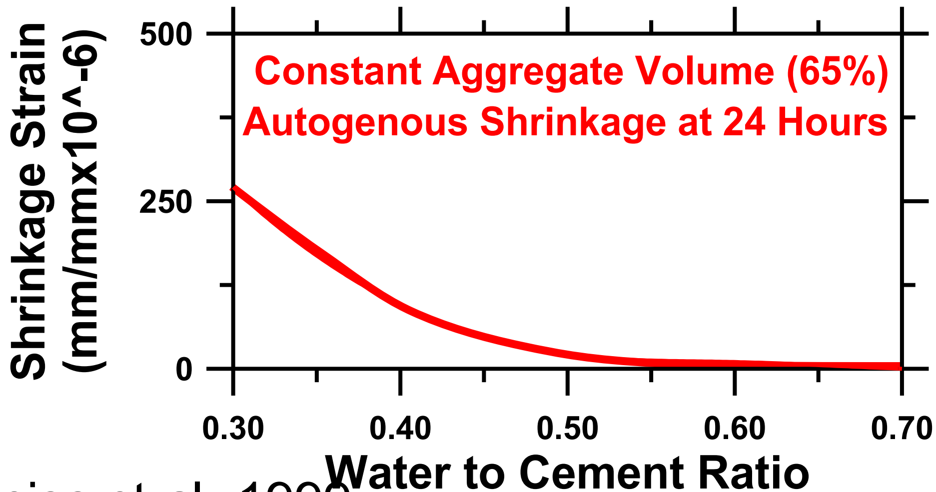
Misconception #1

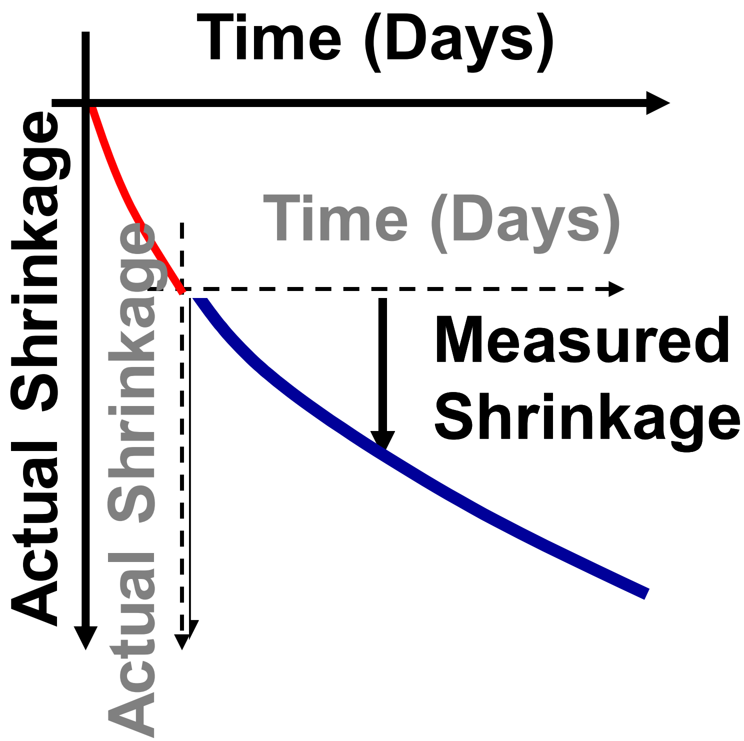
Higher Strength Concrete Has Significantly Lower Shrinkage (Volume Stability)

Measuring Shrinkage Starting Time is Critical





Weiss et al. 1999



After Aitcin 1999

Advantages

- Higher Strength
- Rapid Strength Gain
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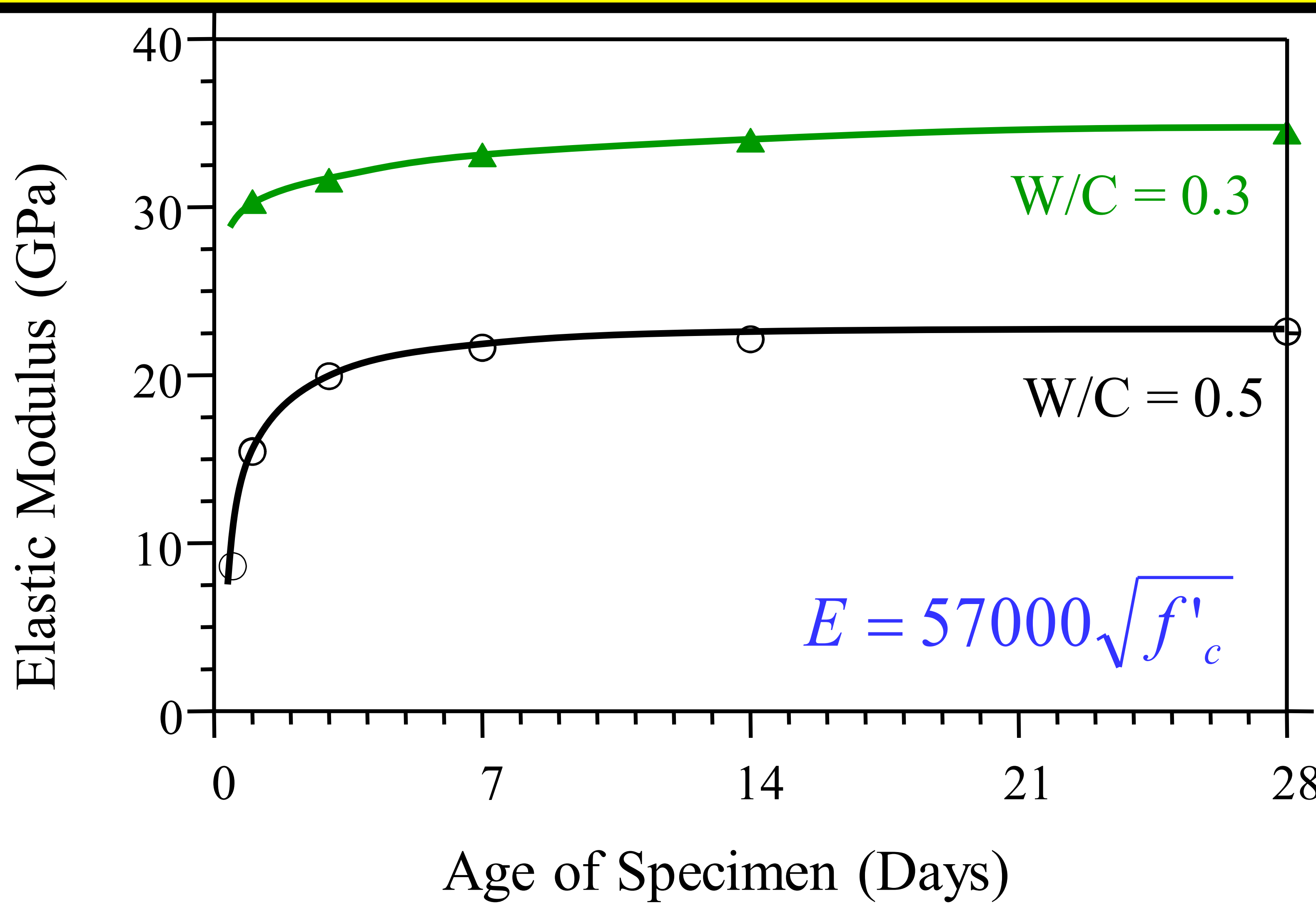
- Lower Creep

Misconception #2

Higher Strength Has Higher Stiffness and That's Always Good

Modulus Development

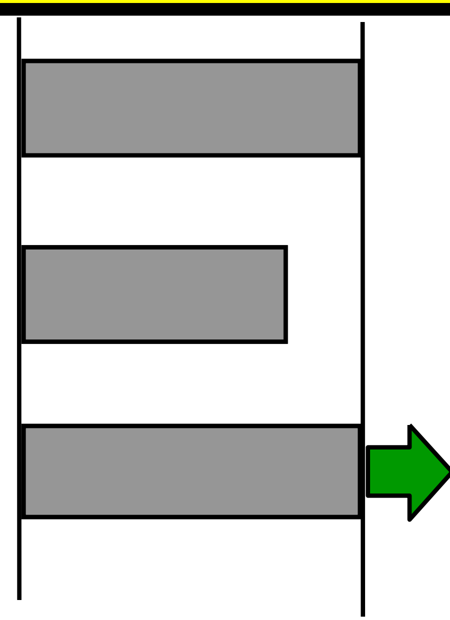


Using Hooke's Law to Compute Stress

Initial Specimen

Shrinkage Effect

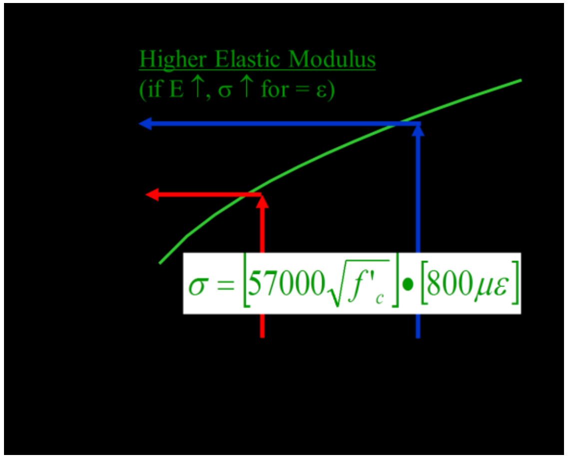
Restraint Effect



Initial Pavement

Disconnect it From The Subgrade

Apply Force to 'Simulate' Subgrade



$$\sigma = E\varepsilon$$

Assumed Shrinkage

$$\sigma = \left[57000\sqrt{f'_c}\right] \bullet \left[800\mu\varepsilon\right]$$

Weiss et al. 1999

Advantages

- Higher Strength
- Rapid Strength Gain
- Low Permeability
- Improved Durability
- Costs
- Less Members
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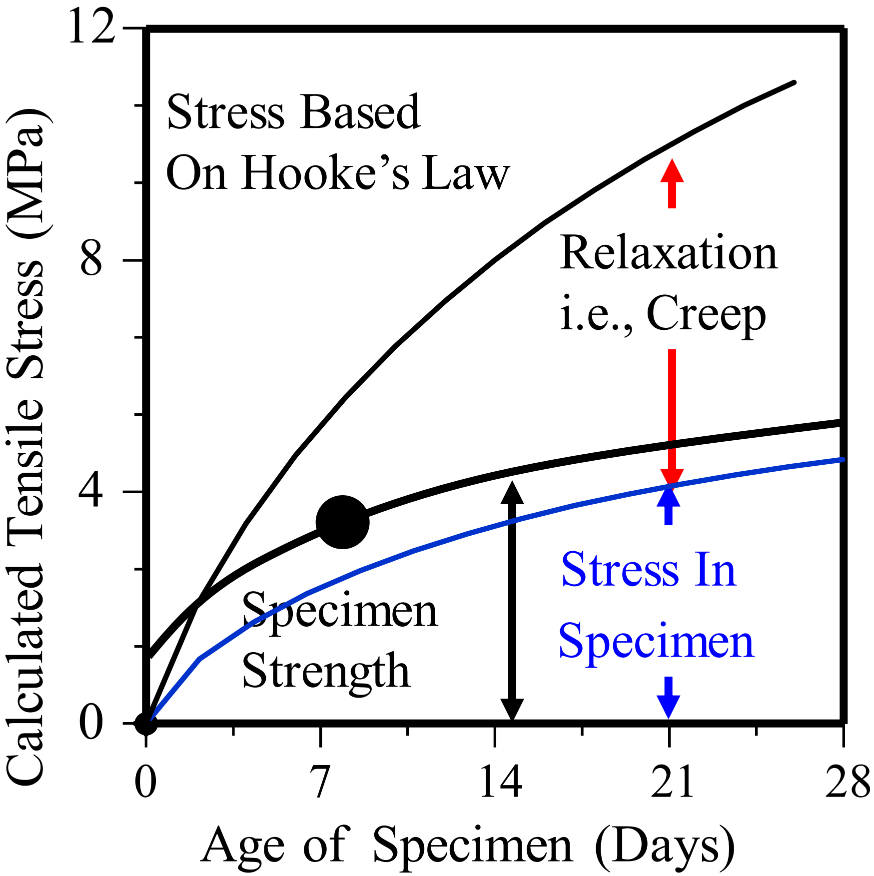
- Toughness
- Higher Modulus
- Lower Creep

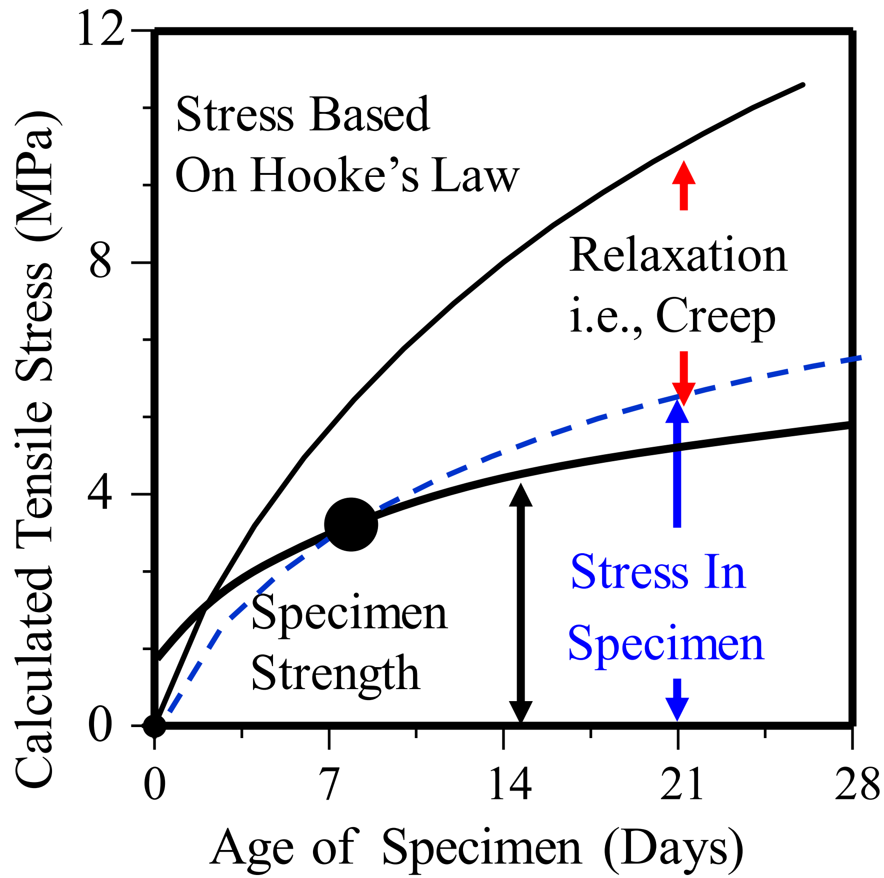
Misconception #3

Higher Strength Has Lower Creep and That's Always Good

Misconception: Lower Creep is Always Beneficial to Performance



Specimen with Lower Creep



Weiss et al. 1999

Advantages

- Higher Strength
- Rapid Strength Gain
- Low Permeability
- Improved Durability
- Costs
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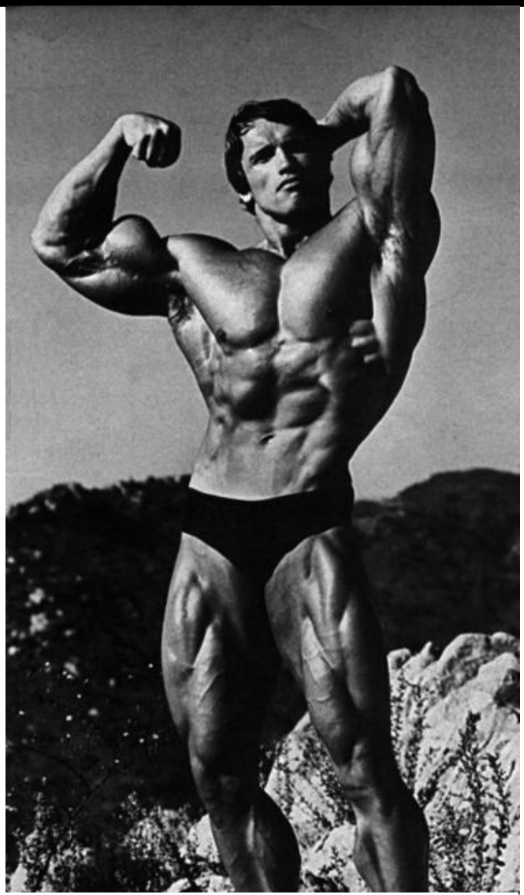
- Volume Stability
- Toughness
- Higher Modulus
- Lower Creep

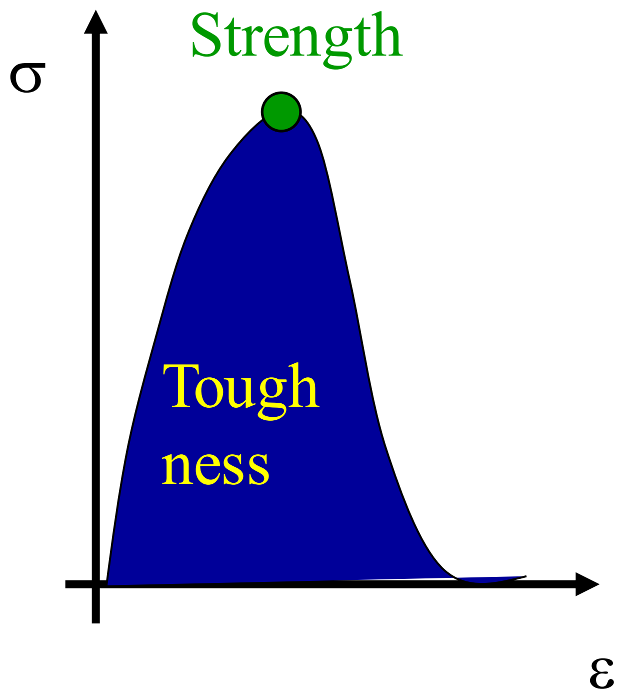
Misconception #4

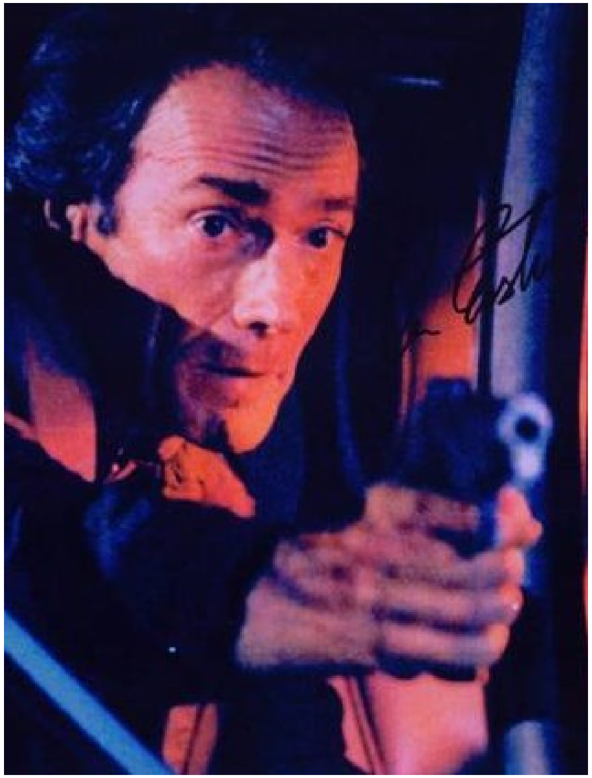
Higher Strength is Tougher Than Conventional Concrete

Strength Versus Toughness



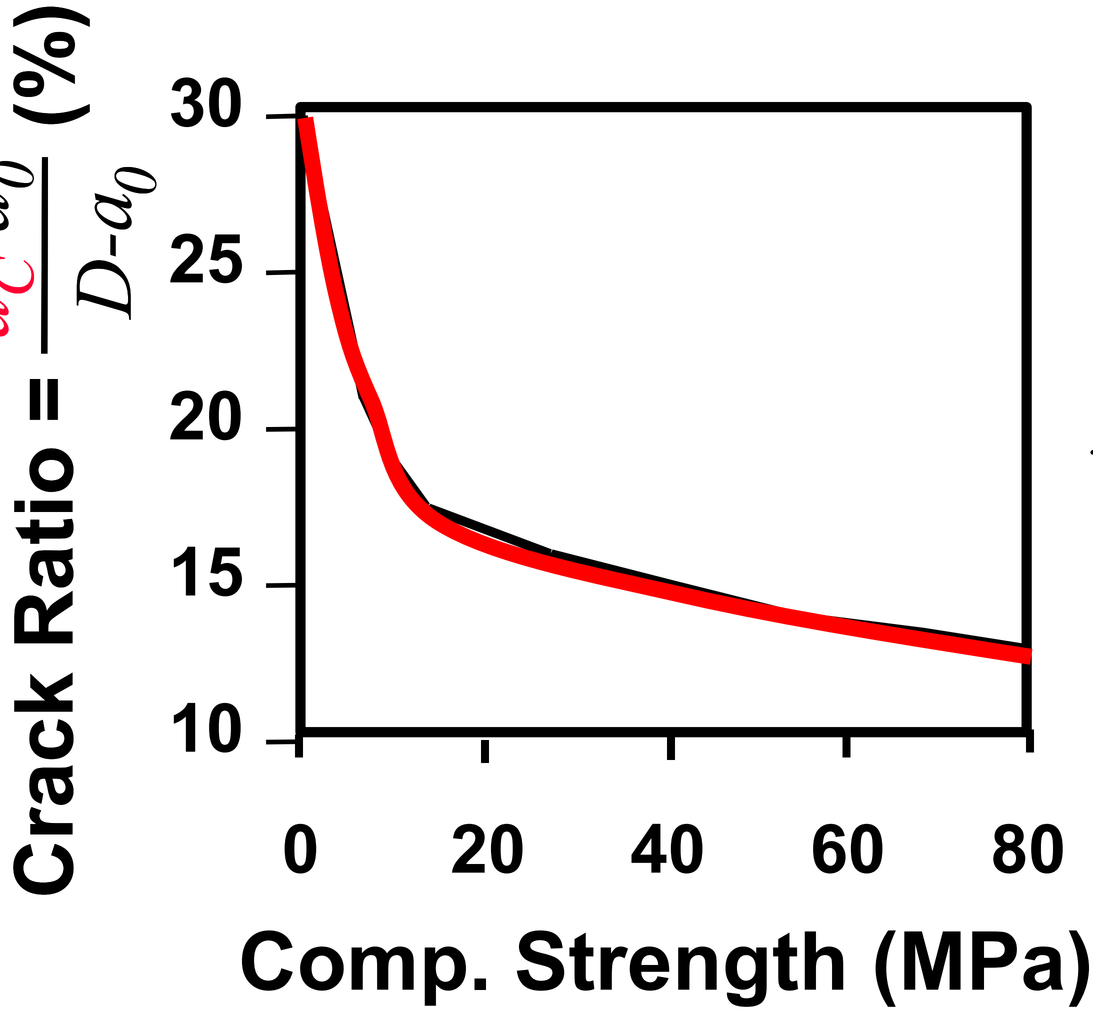
Arnold
Strong

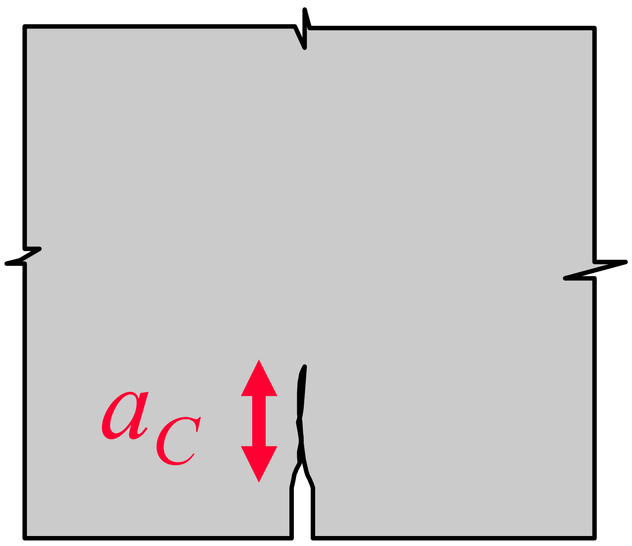




Clint
Tough

Higher Strength Concrete is More Brittle





Higher Strength is More Like Glass

Weiss et al. 1999

Advantages

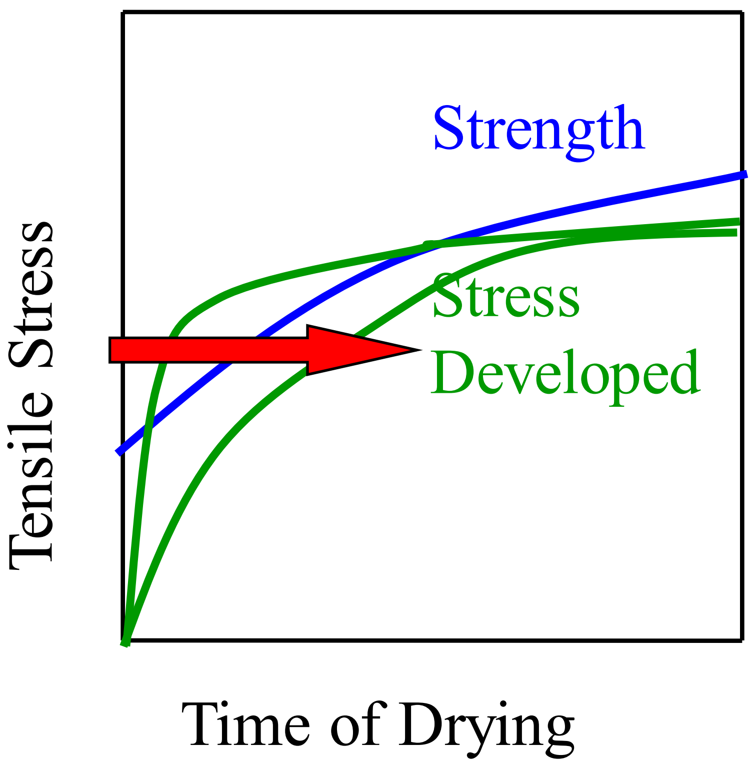
- Higher Strength
- Rapid Strength Gain
- Low Permeability
- Improved Durability
- Costs
- Less Members
- Ease of Placement
- Volume Stability
- Toughness
- Higher Modulus
- Lower Creep

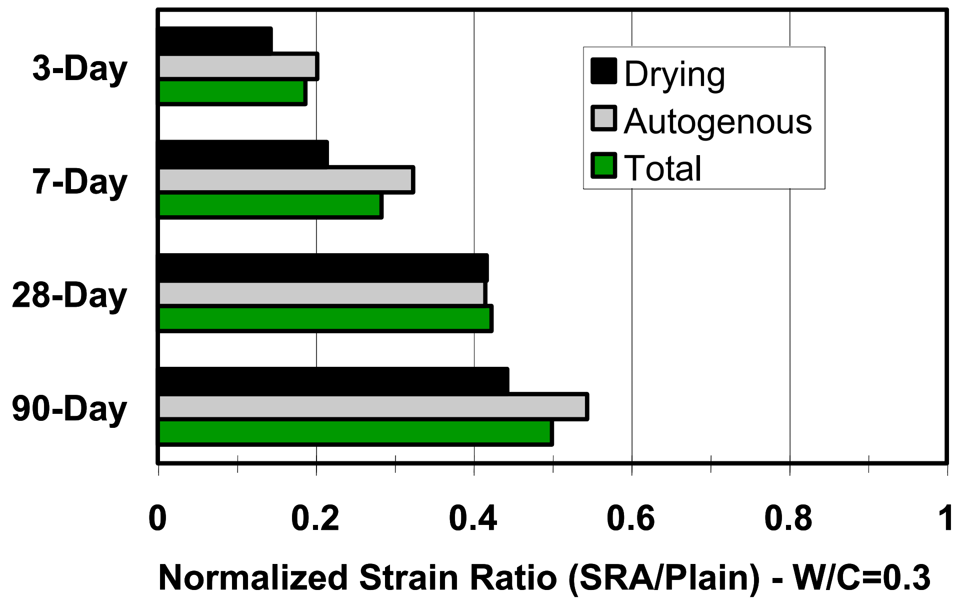
Misconception #5

Higher Early Strength, More Rapid Strength Gain is Always Better

Reducing Stress to Reduce the Potential for Shrinkage Cracking

Reduce Rate



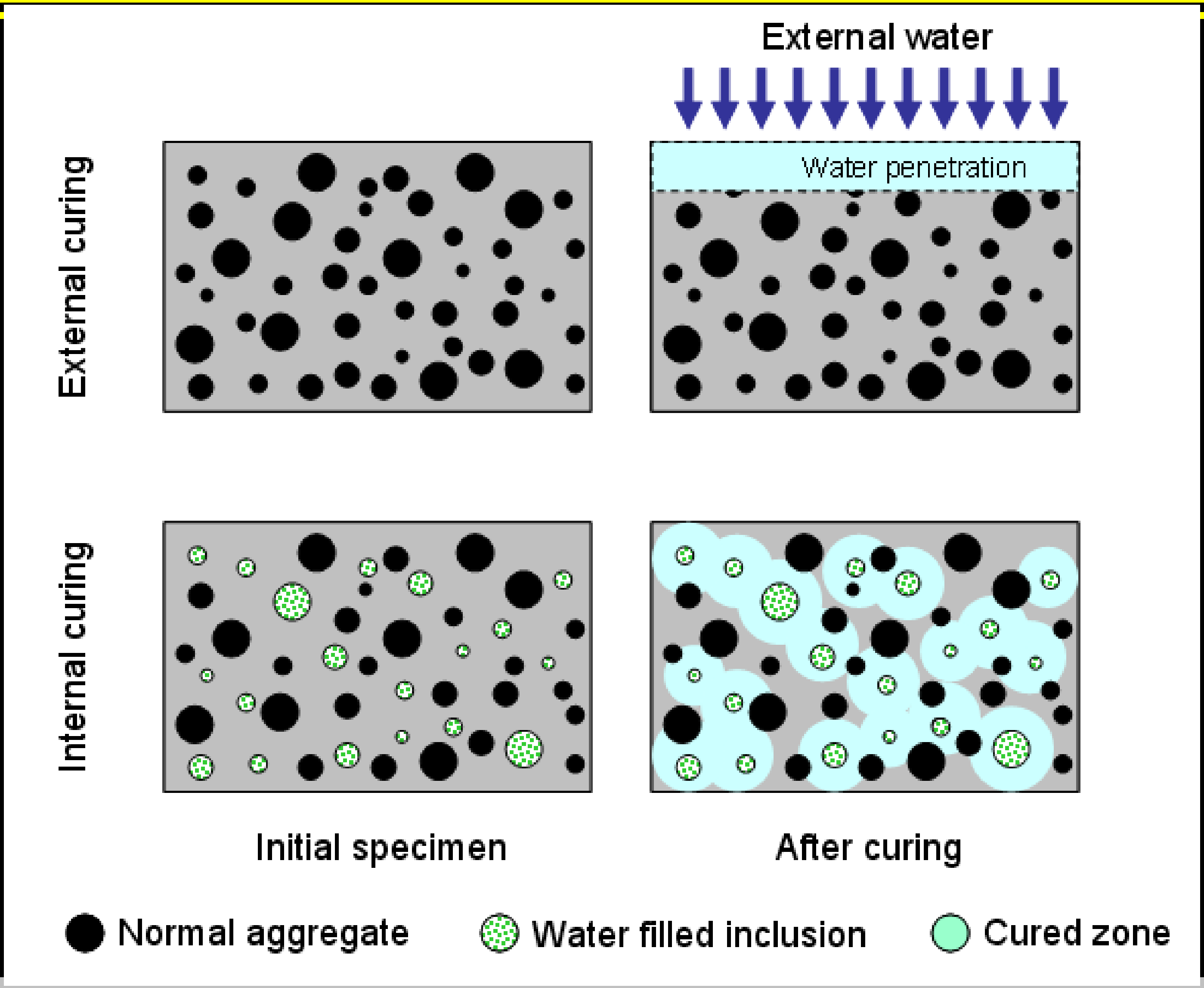


Weiss et al. 1999

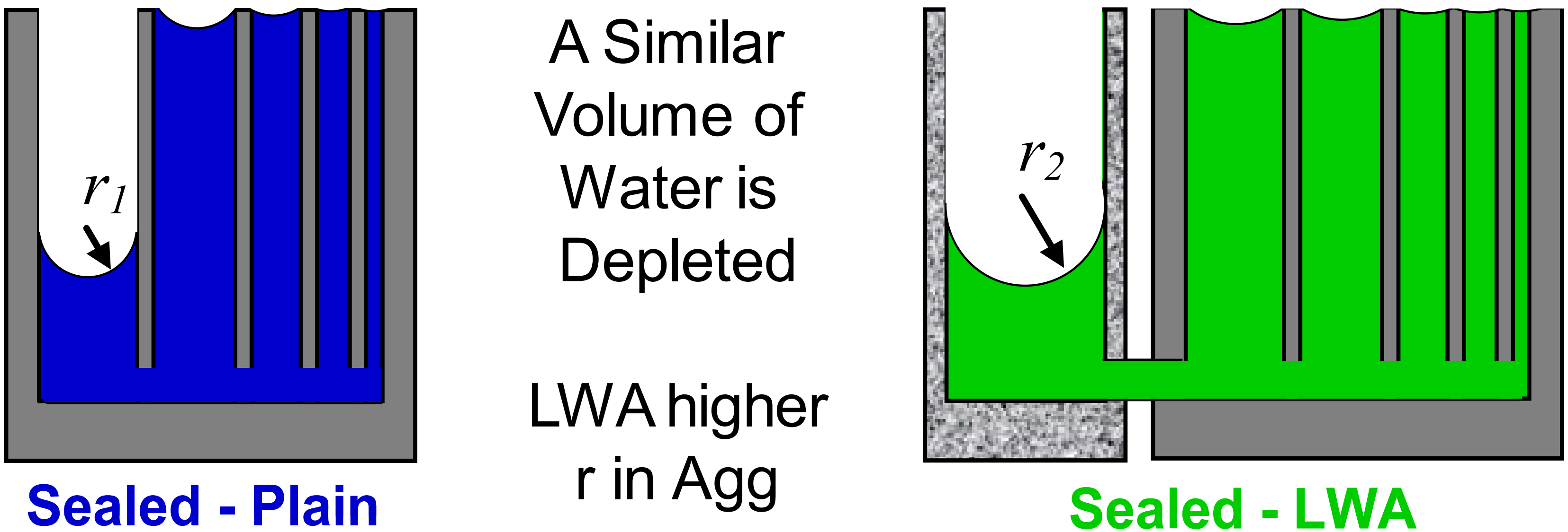
Lets Collect our Thoughts

- People want HSC due to low transport
- HSC can lead to increased cracking
  - Increased shrinkage (typically not measured)
  - No substantial improvement in toughness
  - Reduced ‘creep’ (VE mtl) (reduced relaxation)
  - Increased stiffness
  - Rapid strength gain
- What do we want? low transport and low shrinkage and cracking
- How do we get it? – MP, SRA, Internal curing

Conventional and Internal Curing



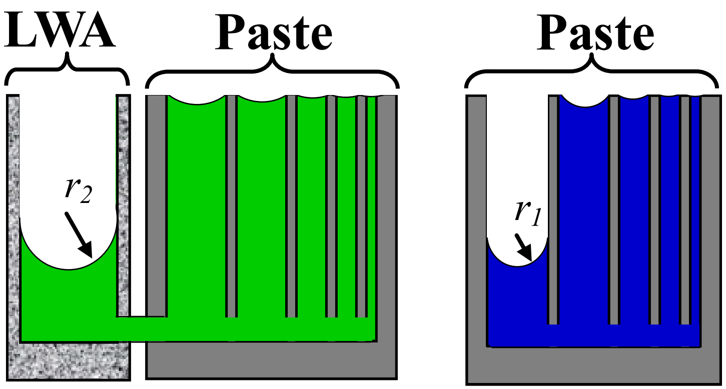
Internal Curing and Pore Size



- Prewetted LWA provides water to the paste and keeps a large pore full
- As a result the pore size that remains full is larger

$$\sigma = \frac{2\gamma \cos\theta}{r}$$

Effect of Internal Curing on Shrinkage

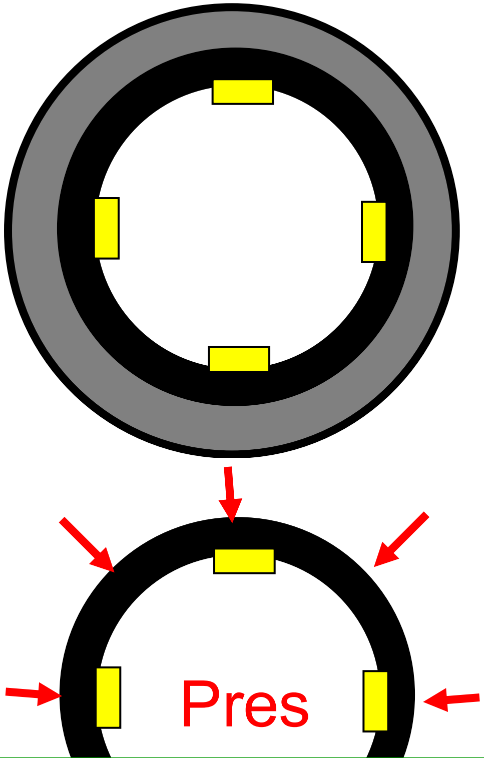


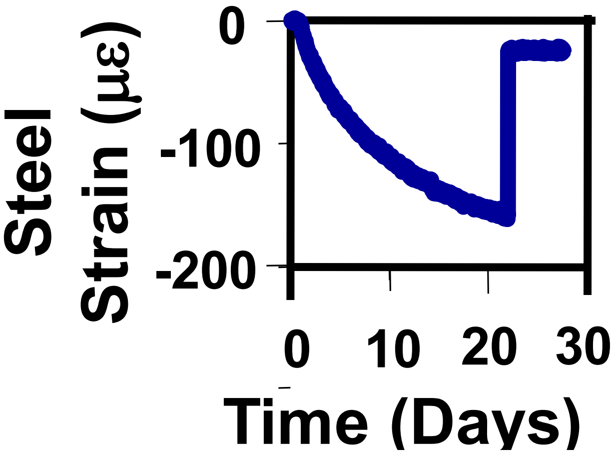
$$\varepsilon_p = \frac{S}{3}\left(\frac{2\gamma}{r}\right)\left(\frac{1}{K_p} - \frac{1}{K_s}\right)$$

- Remaining water will fill in pores
- LWA Pores > Paste Pores

- Modified version of Mackenzie's equation
- Larger pores remain saturated - less shrinkage

Quantifying Stress with the Ring Test





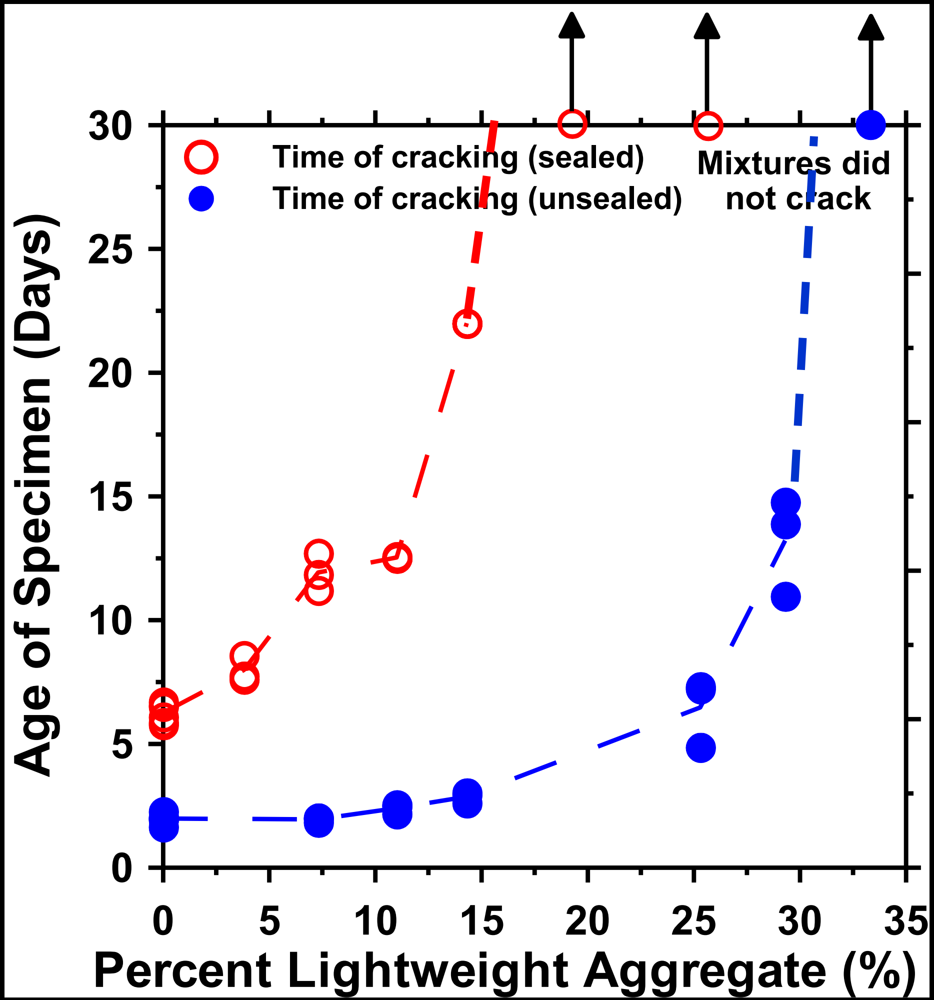
Top & Bottom Drying or Perfectly Sealed

$$\sigma_{Concrete}(t)\Big|_{r=R_{IC}} = \varepsilon_{Steel}(t) E_S \frac{\left(R_{OS}^2 - R_{IS}^2\right)}{2R_{OS}^2} \frac{\left(R_{OC}^2 + R_{IC}^2\right)}{\left(R_{OC}^2 - R_{IC}^2\right)}$$

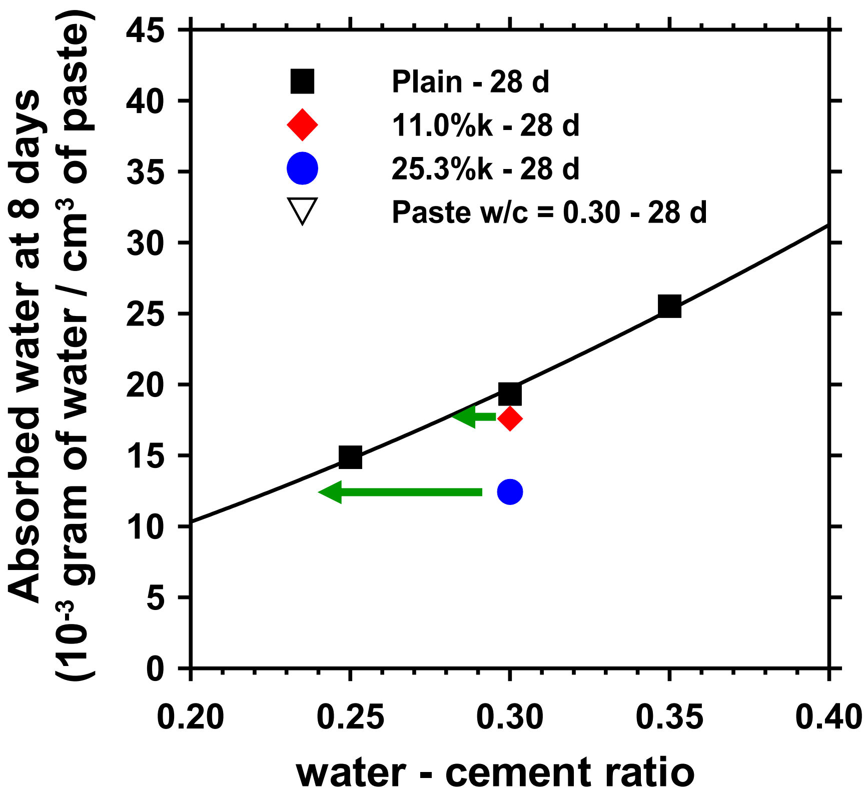
Weiss and Furgeson 2001, Hossain and Weiss, 2002

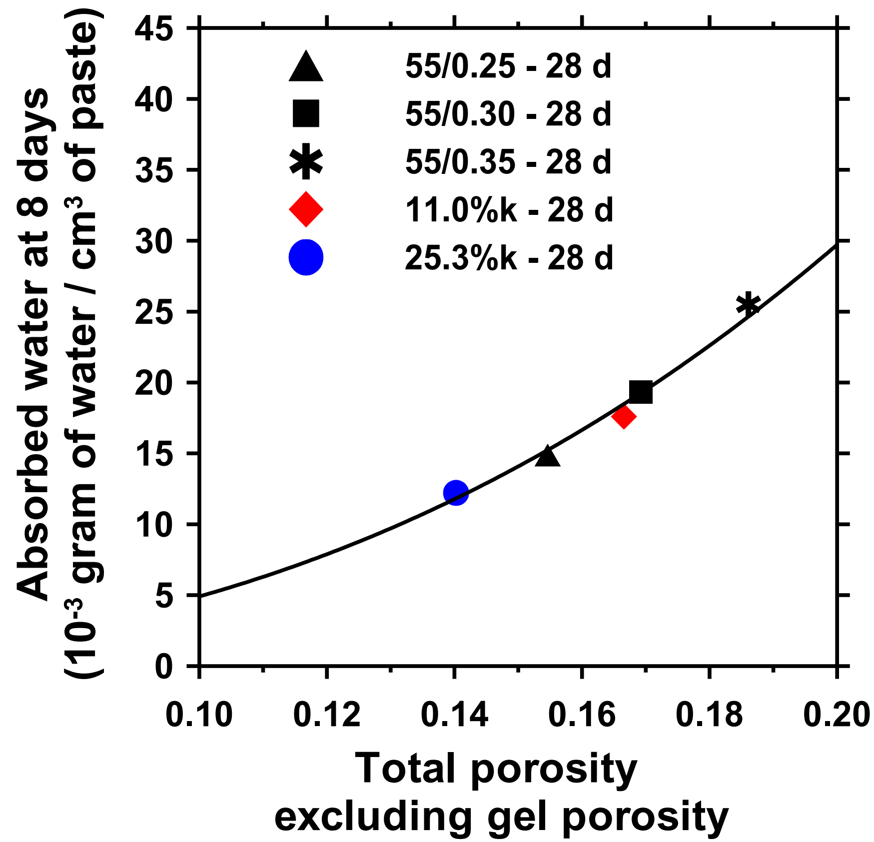
Restrained Shrinkage

- We can see that cracking is more likely than in the sealed case
- Appears logical
- Shrinkage rate decreases and can improve crack resistance



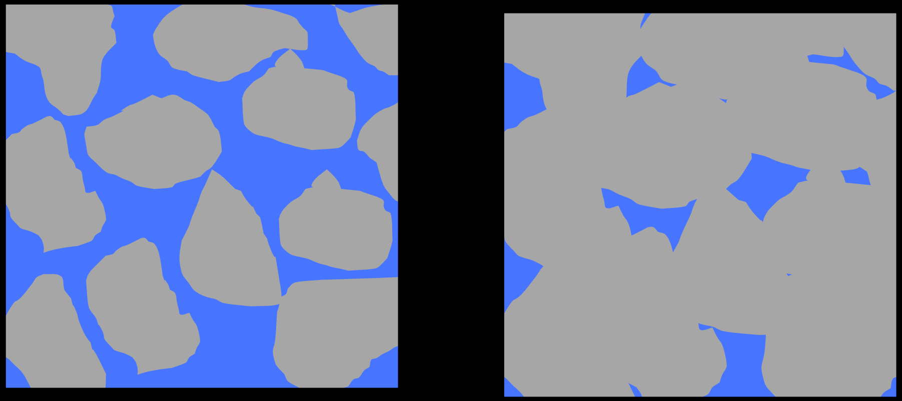
Benefit of Internal Curing



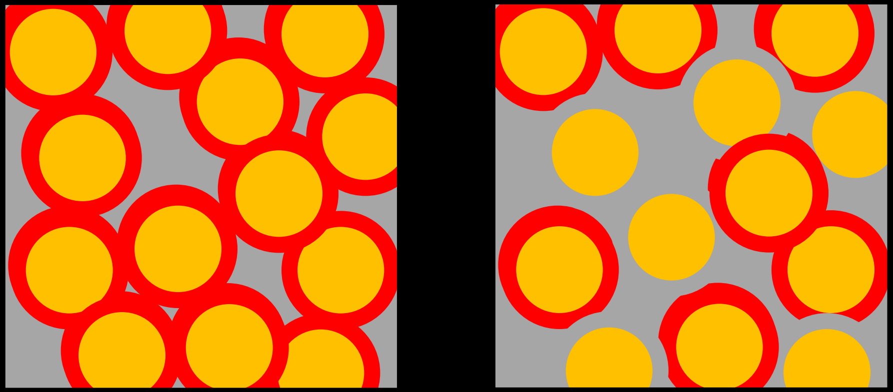


Two Benefits

- Reduced porosity due to increased hydration



- Reduced connectivity of interfacial transition zones



Internal Curing (Best Estimate)

Indiana Field Trials - Conventional and IC mixtures in Sister Bridges

- Implemented in Monroe County Bridges in 2010
- Bridges cast using conventional ready mix concrete and conventional procedures
- Shows that this is a ‘very off the shelf technology’ – replace some FA with FLWA

Monroe County IN (DiBella et al. 2012)

- Simple Change in Mixture Proportions

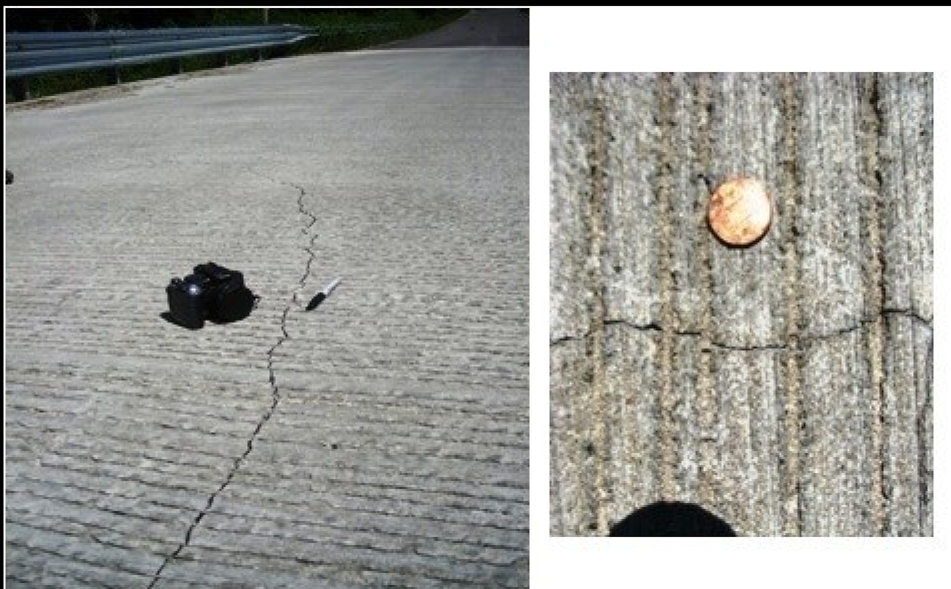
	Cement Content	W/C	Fine Aggregate	Fine LWA	Coarse Aggregate	Mixture Water	Water in LWA	WR	AE
	(kg/m³)		(kg/m³)	(kg/m³)	(kg/m³)	(kg/m³)	(kg/m³)	(%)[A]	(%)[A]
Plain Concrete	390	0.39	726	-	1046	152	-	0.22	0.08
Internally Cured Concrete	390	0.39	313	270	1046	152	25	0.22	0.08

- IN - Plain Slabs Cracked; IC did not crack

- IC has lower transport properties

Time [days]	Charge Passed [Coulombs]			
	Plain Concrete	Standard Deviation	Internally Cured Concrete	Standard Deviation
28	4252	116	3822	159
56	2863	560	2458	55
91	3174	450	2065	113

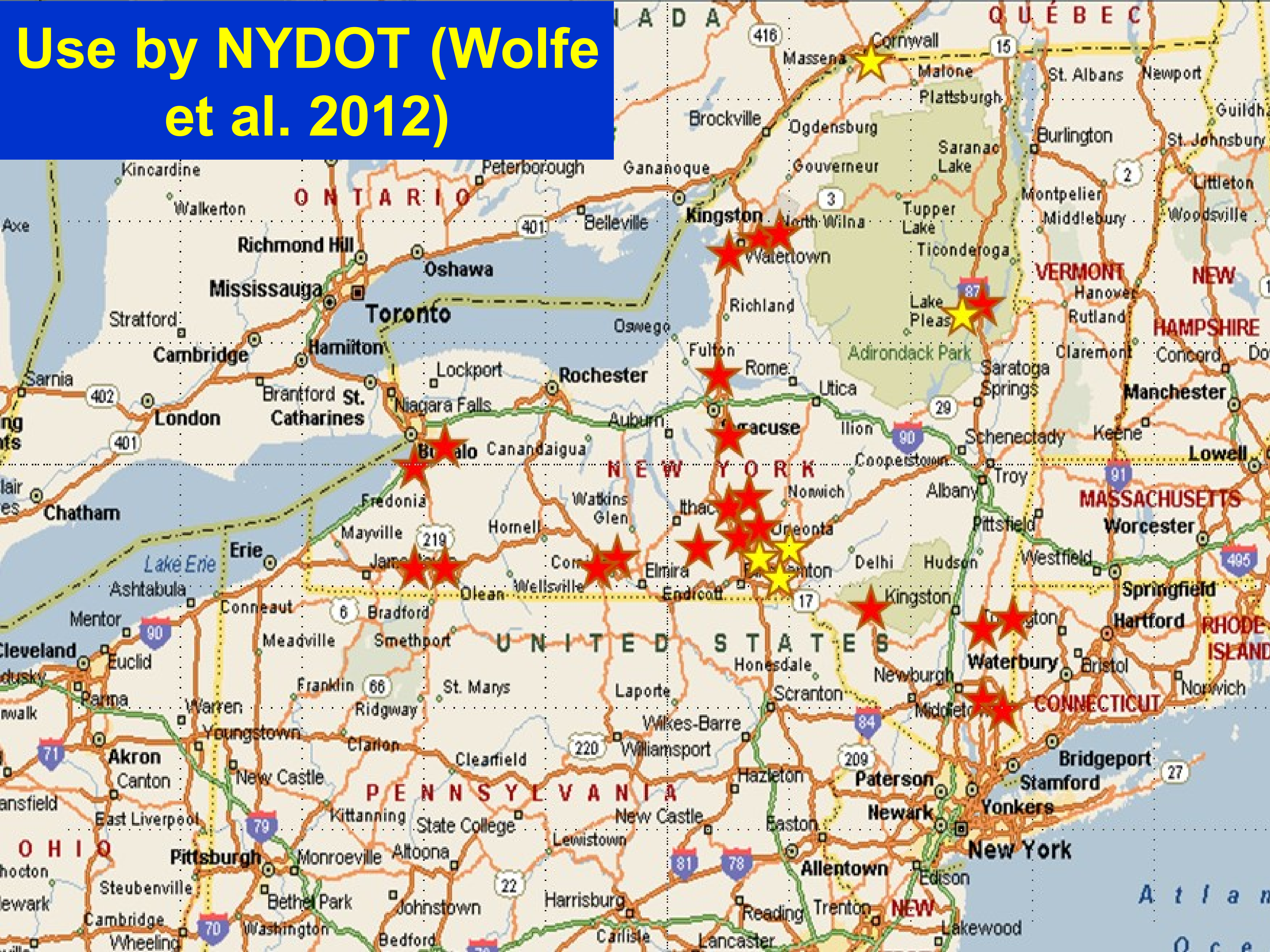
Field comparison (Monroe Co In)



Plain bridge deck
(Monroe Co.)
1 year after casting.

Internally cured bridge deck (Monroe Co.)
"Crack Free 18+ mos after Casting"

Use by NYDOT (Wolfe et al. 2012)



Tonowanda NY

Comments from the Field

- **Lanny Kipp, C&C Ready-Mix, NY**
- Didn’t see any issues batching, pumping, or finishing
- Soaking the stockpile for several days, mixing and blending is important for uniform moisture
- Remove the water source the day before to allow free water to drain
- Once the LWA is in the bins, loss to evaporation would be minimal
- LWA weighed first to insure proper amt
- Loading slowed slightly due to the addition of a 4th aggregate

C & C Ready-Mix Corporation
Quality Building Products Since 1951

Comments from the Field

- **Jeff Jones, Buffalo Redi Mix, NY**
- **I saw no problems from the producer's, pumper's and even the contractor's perspective**
- **Air was not an issue pumping**
- **LWA worked fine in the plant. We ran 200 to 300 yards at a time.**
- **No issues with it hanging up**
- **I've worked with other low cement mixes and think that this is by far the best option**
- **I wouldn't hesitate to do it again**
- **Manual moisture, cooked 20 mins**

BUFFALO CRUSHED STONE, INC.

Tonwanda (190/I290) NY Results

- Similar RCPT results
  (DiBella et al 2011)
  *note cond. LWA in test

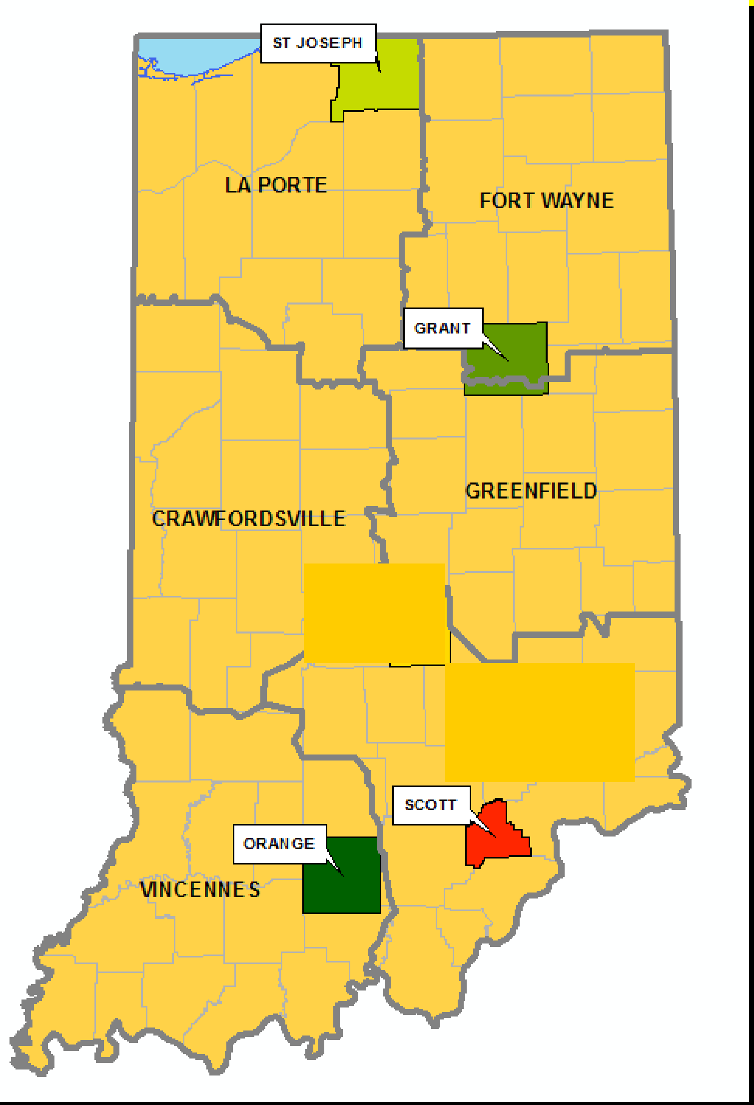
	NY Lisle		NY Tonawanda	
Time [day]	Charge passing [Coulombs]		Charge passing [Coulombs]	
	Plain Concrete	IC Concrete	Plain Concrete	IC Concrete
28	535	423	572	570
56	373	406	342	313
91	357	392	308	301

- Similar fresh properties
- Similar Strength (Wolfe et al 2012)

	Class HP	Class HP-IC
Comp. Str. 7 day	3,040 psi	3,500 psi
Comp. Str. 28 day	4,677 psi	4,683 psi
Comp. Str. 56 day	5,343 psi	5,417 psi
Concrete Density	140.2 pcf	135.2 pcf
Air Content	5.5 %	6.0 %
Slump	5.0”	4.5”

ICHPC Coming to a County Near You for Full Scale Experiments (Carboneau)

- B-30498 SR 933, St. Joseph County, LaPorte District, October 2012
- B-33379 I-69, Grant County, Fort Wayne District, January 2013
- B-34199 US 150, Orange County, Vincennes District, February 2013
- B-35326 US 31, Scott Co, Seymour District, March 6th, 2013



Summary

- People want HSC due to low transport
- HSC can lead to increased cracking
- To reduce the potential for shrinkage cracking we can reduce paste volume, use a surface tension modifier (SRA) or use internal curing
- Internal curing – uses prewetted LWA
- Internal curing use is starting to increase
- There are 4 experimental projects occurring across Indiana (other states as well)